Examining the Connection Between Polycyclic Aromatic Hydrocarbon and Physical Processes in Ultra Luminous Infrared Galaxies

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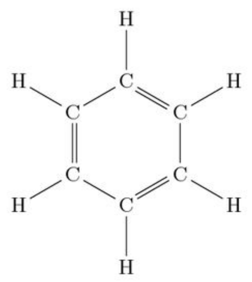
Abstract

We examine the relationship between **Polycyclic Aromatic Hydrocarbon** features, and observable physical characteristics for a sample of 42 local ULIRGs observed using the Infrared Spectrograph on the **Spitzer Space Telescope**. A radiative transfer model allows us to compare these features to the starburst, spheroid, and AGN luminosity of these ULIRGs. We present models between PAH emissions and component luminosities, as well as relations between PAH EW and AGN luminosity. We observe strong correlations between PAH Luminosities and starburst luminosity, as well as Star Formation Rate, supporting the theory that PAH emission features are the result of gas in the ISM being heated by photons from young stars. We find a significant anti-correlation between PAH EW and AGN luminosity, suggesting that AGN contribute to a bright continuum, making PAH emissions more difficult to observe.

Introduction

- **What is a ULIRG?**
  - Galaxies with Infrared (IR) luminosities greater than 10^{12} $L_{\odot}$
    - Sparse within z< 0.03
    - Several hundred per square degree for z ≥ 1 (Farrah et. al., 2013)
  - Power source behind IR emission is believed to be a combination of starbursts and Active Galactic Nuclei (AGN).
- **Why Study ULIRGs?**
  - The bulk of stellar and black hole mass assembly occurs at high redshift (Madau and Dickinson, 2014).
  - A large fraction of mass assembly occurs in very infrared luminous bursts of activity within ULIRGs.
  - Understanding formation processes of ULIRGs means understanding formation processes of galaxies as a whole.
- **What are PAHs? Why study them?**
  - Believed to be produced and heated by recent star formation (Peeters, 2005).
    - Ultraviolet and optical photons radiate off of stars and heat PAH molecules in the interstellar medium (ISM).
    - The atoms in the molecules become excited, begin vibrating, and produce IR emissions.



Methodology

- **The Data**
  - Obtained using the Infrared Spectrograph on the *Spitzer* space telescope.
  - Sample of 42 ULIRGs with flux densities ≥2 Jy and z < 0.23.
- **Radiative Transfer Model**
  - Allows us to decompose the IR luminosity into several components:
    - AGN luminosity
    - spheroid (host galaxy) luminosity
    - starburst luminosity
- **Kendall Rank Correlation Coefficient**
  - Used to quantify the strength of the relationship between two sets of data; does not assume any sort of model.
    - If a statistically significant (P ≤ 0.05) correlation is found, we further explore the relationship by creating a model.
- **Developing a Model**
  - SciPy Orthogonal Distance Regression (ODR)

$$log(L_{Component}) = \alpha \cdot log(L_{Observable}) + \beta$$

  - We analyze the effects of a third variable,including properties of starburst (starburst age, initial optical depth of star formation, and the time constant of the exponentially decaying SFR), AGN (inclination angle, opening angle, and UV optical depth), and silicate depth on the scaling relationships developed.

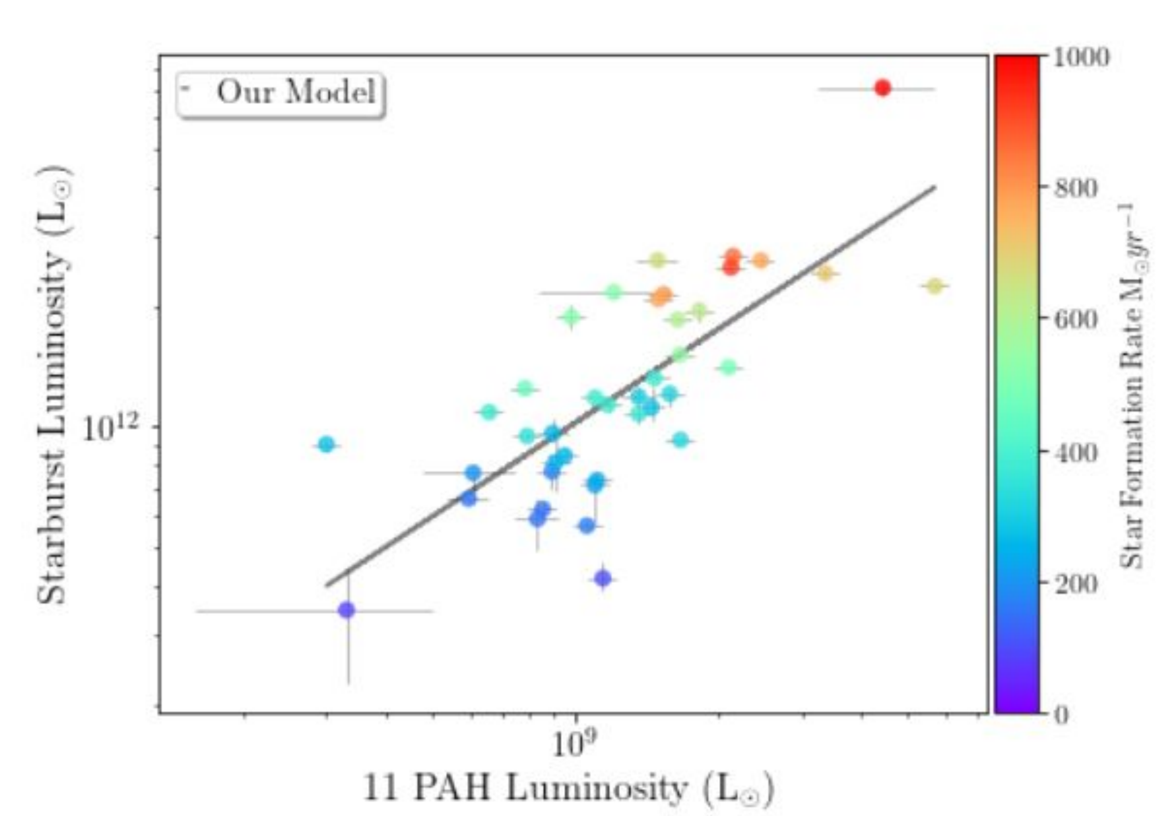


Figure 1: Starburst luminosity versus 11 μm PAH luminosity, color-coded by star formation rate. *Graphing of the same relationship for 6.2 μm PAH luminosity not pictured

Figure 2: 6.2 μm PAH luminosity versus the sum of starburst and spheroid luminosity. Models from Cortzen et al. (2019) are plotted atop of our data, along with our own model. *Cortzen only created models for 6.2 μm PAH luminosity; there is no analogous graph for 11 μm PAH luminosity

Results

- **PAH Emissions**
  - We find a positive correlation between Starburst Luminosity and PAH emissions:

$$log(L_{Sb}) = (0.724 \pm 0.114) \cdot log(L_{6.2\mu m}) + (5.425 \pm 1.050)$$

$$log(L_{Sb}) = (0.785 \pm 0.111) \cdot log(L_{11\mu m}) + (4.949 \pm 1.007)$$

    - Slope is consistent with but noticeably below unity.
  - We also find a positive correlation between SFR and PAH emissions:

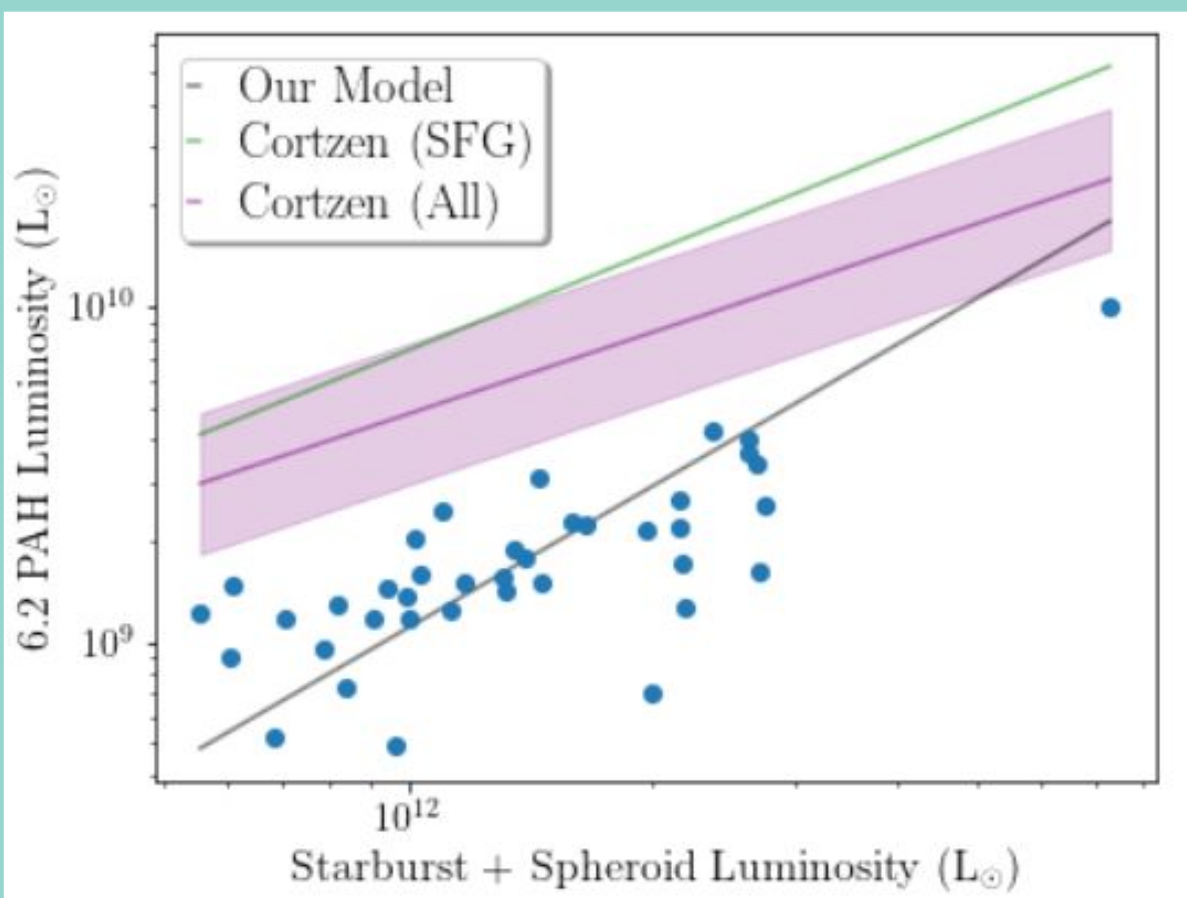
$$log(SFR) = (0.875 \pm 0.124) \cdot log(L_{6.2\mu m}) + (-5.519 \pm 1.147)$$

$$log(SFR) = (0.880 \pm 0.133) \cdot log(L_{11\mu m}) + (-5.467 \pm 1.205)$$

  - We fine a positive correlation between spheroid luminosity and PAH emissions, but it is unlikely that PAH emissions come from the host galaxy.
  - There is a positive correlation between PAH luminosity and raw total luminosity, but no such correlation is found between PAH luminosity and corrected total luminosity.
- **Comparison to Literature**
  - Cortzen et al. (2016) see figure 2
    - ULIRGs are consistent outliers
  - Maragkoudakis (2018), Shipley (2016) see figure 3
    - Differences in relations due to sample & methods
- Equivalent Width
  - We find an anti-correlation between PAH Equivalent Width (EW), and (raw) AGN Luminosity:

$$log(L^r_{AGN}) = (-0.609 \pm 0.099) \cdot log(6.2\mu mEW) + (11.023 \pm 0.088)$$

$$log(L^r_{AGN}) = (-0.525 \pm 0.111) \cdot log(11\mu mEW) + (11.198 \pm 0.082)$$



Conclusion

- We confirm that PAH emissions are the result of star formation.
- These emission features are harder to detect when a strong continuum is present, and AGN can be the source of this continuum.
- We present new relations between PAH emissions and SFR, starburst, spheroid, and total luminosity.
- We present relations between PAH EW and AGN luminosity.
- These relations are best suited to convert between PAH emission and SFR, starburst luminosity etc. in very luminous systems.
- Our models are reasonably different than those derived in other works based on sample, methods etc.
- We will further explore the relationship between emission features and physical processes in ULIRGs by examining fine structure lines

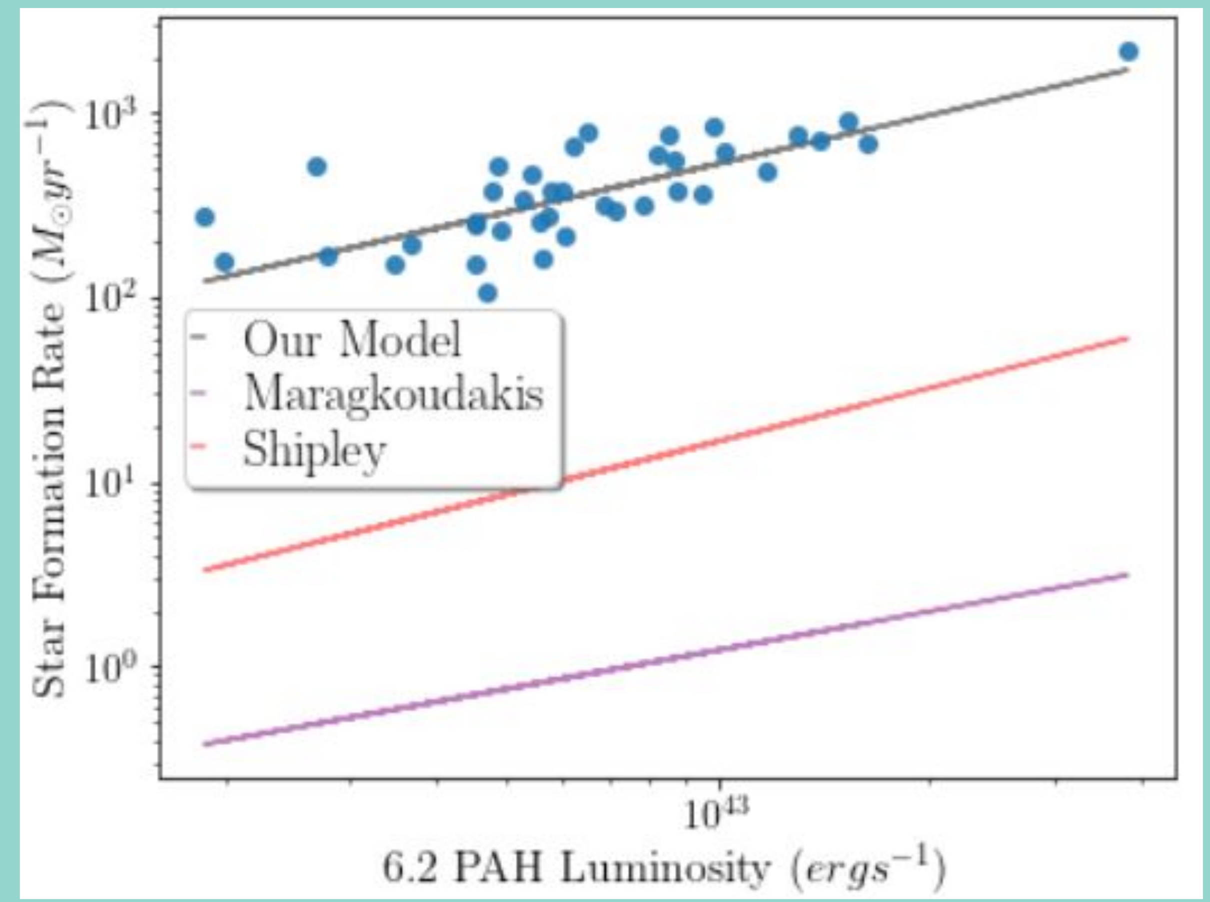
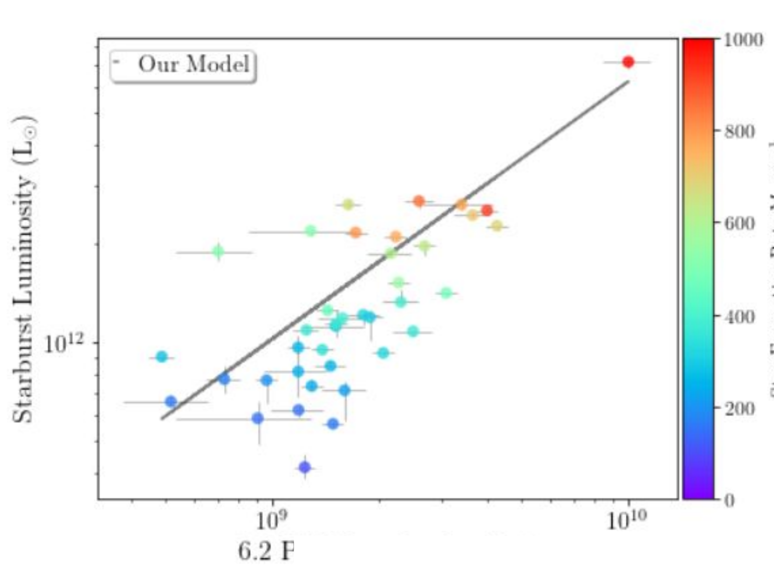
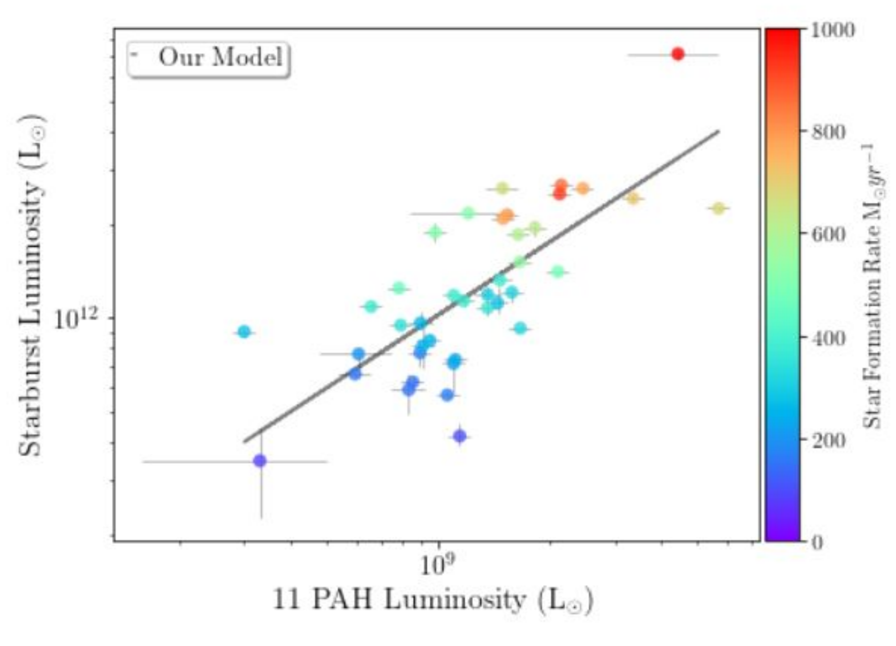


Figure 3: Star formation rate versus 6.2 μm PAH luminosity. Models derived in Maragkoudakis (2018) and Shipley (2016) are plotted along with our data and our own model. *Analogous plot for 11 μm PAH luminosity not pictured.

Acknowledgements

LR acknowledges support from Research Experience for Undergraduate program at the Institute for Astronomy, University of Hawaii-Manoa funded through NSF grant #2050710. LR would like to thank the Institute for Astronomy for their hospitality during the course of this project.


Our Model
Starburst Luminosity (L⊙)
10^12
10^9
10^10
6.2 F
Star Formation Rate M⊙yr^-1
0
200
400
600
800
1000


Our Model
Starburst Luminosity (L⊙)
10^12
10^9
11 PAH Luminosity (L⊙)
Star Formation Rate M⊙yr^-1
0
200
400
600
800
1000